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Henry Waelti
South Dakota State University

Wesley F. Buchele
Iowa State University

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Factors Affecting Corn Kernel Damage in Combine Cylinders

Henry Waelti and W. F. Buchele
MEMBER ASAE FELLOW ASAE

SINCE the introduction of the corn head attachment and other field-shelling equipment, many farmers have changed from ear-corn harvesting systems to high-moisture, field-shelling systems. The use of the grain combine and field-shelling attachment for corn pickers has brought into focus the problem of mechanical damage to corn kernels.

When field-shelling equipment for corn was first developed and introduced, kernel damage was relatively low because the ears were harvested and shelled at low-moisture contents. But the introduction of grain driers has made it feasible to harvest corn in the 20 to 35 percent kernel-moisture range. Kernel injury during shelling, however, increases rapidly at kernel moistures above 20 percent.

Kernel injury affects both short-term and long-term corn storage. Saul and Steele (6) reported that field-shelled, high-moisture corn could not be stored more than a few hours without some deterioration in quality. Machine-shelled corn, with 29 percent mechanical damage, deteriorated two to three times faster than damage-free, hand-shelled corn of the same moisture content. An economic analysis showed that the drying-energy cost (excluding equipment cost) was six to seven times greater for damaged, field-shelled corn than for damage-free, hand-shelled corn.

Little is known about the factors contributing to mechanical kernel damage during the shelling process. Most threshing research has shown that high cylinder speed is the chief factor causing grain damage (1, 2, 3, 4, 5, 8)*. Other machine parameters, such as cylinder-concave clearance and type of cylinder bars, seem to affect kernel damage only slightly.

Sehgel and Brown (7) reported that, when threshing hard-shelling ears, there was not only more cob splitting but

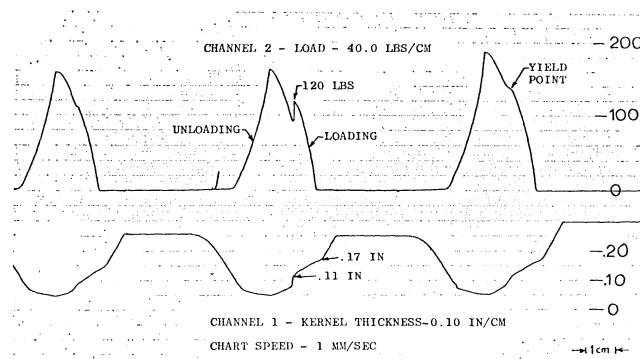


FIG. 1 Oscillograph chart of typical kernel compression tests.

also an increase in mechanical kernel injury. Their studies suggested that morphological ear properties, that are inherent variety characteristics, affect mechanical damage to kernels and that combining ability and cob quality of the hybrids could be predicted from the characteristics of the inbred parents.

It is evident, therefore, that if the relationships of physical and morphological properties of the kernels and cobs and their contribution toward kernel damage were known, the plant breeder could make use of this knowledge when selecting parents with desirable physical and morphological properties.

Objectives

Since kernel damage from the shelling operation depends greatly on the properties of the kernels and cobs, the objectives of this research were:

1 To determine physical and morphological properties of the kernels and cobs.

2 To correlate through experiments the physical properties and morphological characteristics to kernel damage as a result of the shelling operation.

Consideration of Variables

Following is a list of the variables used in the study:

1 Dependent variable:

\hat{Y} , damage - percentage by weight of kernels with breaks, cracks or other injuries in their seed coat

2 Independent variables:

Y_1 , kernel moisture - percentage determined by oven-drying at 102°C for 24 hr

Y_2 , detachment force - pounds force needed to pull kernels off the cob in an axial direction of the kernels
 Y_3 , kernel strength - strength of kernels in compression in a flat position when rupture of the seed coat occurred

Y_4 , initial thickness - kernel thickness (flat position) at zero load

Y_5 , final thickness - kernel thickness at failure (seed coat rupture)

Y_6 , cob moisture - percentage determined by oven-drying at 102°C for 72 hours

Y_7 , cob strength - maximum compressive strength of a one-in. long cob section with load applied perpendicular to cob axis

Y_8 , initial diameter - diameter of cob section at the compressive load of 10 lb

Y_9 , final diameter - diameter of cob section when failure occurred

Y_{10} , kernel area - cross-sectional area for the flat side of the kernel

Y_{11} , kernel strain - strain at failure for compression test

Y_{12} , kernel stress - strength of kernels (Y_3) divided by kernel area (Y_{10})

Y_{13} , cob strain - strain of cob section at failure for compression test

Y_{14} , Rachis-pith ratio - diameter of smooth cob (rachis) divided by diameter of pith

Y_{15} , ear length - length of ears used in laboratory shelling tests

Y_{16} , ear diameter - average diameter of ears used in lab shelling tests

Determination of Physical Properties

Ears used in the experiment were randomly selected from a special section of a field that was part of a corn-

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The authors—HENRY WAELTI and W. F. BUCHELE—are, respectively, associate professor of agricultural engineering, South Dakota State University and professor of agricultural engineering, Iowa State University.

* Numbers in parentheses refer to the appended references.

harvesting experiment. The field consisted of five varieties: Pioneer 3618, 3558, 3414, 3376, and 3306. These varieties will be referred to as varieties 1, 2, 3, 4, and 5, respectively. Varieties 2 and 4 were also planted three weeks after their first planting date, and these will be referred to as varieties 2L and 4L. Testing was spread throughout the harvesting season to obtain data over a large range of moisture content. For each variety, data were obtained from 12 ears.

Detachment force was determined with a Chatillon dial push-pull gage, model DPP-10. A sharp hook at the end of the pull rod was pushed into the soft embryo region of each kernel and then pulled rapidly in radial direction such that the rachillae failed in tension. The maximum force required was registered on the gage dial. To eliminate friction forces between kernels, a row of kernels along the ear axis was removed before readings were taken, thus eliminating the wedging effect of the kernels.

Strength tests were conducted with a modified Rinck-McIlwaine valve spring tester driven with a cable. Loading rate was 0.0158 in. per second. A strain-gage — cantilever-follower-beam was used in conjunction with the bottom plate to detect the force on the plate through the use of a calibrated strain-gage bridge. The top and bottom plates were inter-connected with a linear potentiometer distance transducer (LPDT). The signals from the LPDT and the strain-gage cantilever beam were fed into a two-channel Beckman type RS dynagraph. One channel recorded the force between the plates and the other the distance between them.

Individual kernels were placed between the plates in a flat position. Load and displacement were recorded throughout the entire run with a chart speed of 1 millimeter per second. Samples of typical recordings are shown in Fig. 1. The force on the kernels increased until kernel breakage occurred and then decreased for a very short time before increasing again; thus a yield point was established. At high

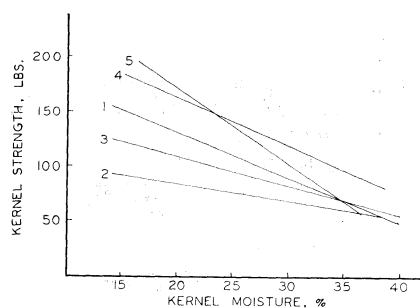


FIG. 2 Relationship of kernel yield-point strength and moisture content for varieties 1 through 5.

TABLE 1. MEAN VALUES OF KERNEL PROPERTIES FOR VARIETIES 1 THROUGH 5

| Property | Variety | | | | | Region | | | Least significant difference, 5 percent level |
|---------------------------|---------|-------|-------|-------|-------|--------|--------|-------|---|
| | 1 | 2 | 3 | 4 | 5 | Butt | Middle | Tip | |
| Moisture content, percent | 26.2 | 22.9 | 25.1 | 25.4 | 22.8 | 25.8 | 24.1 | 23.6 | 9.0 |
| Detachment force, lb | 3.77 | 2.57 | 3.64 | 3.16 | 3.78 | 3.48 | 3.42 | 3.26 | 1.04 |
| Strength, lb | 104.6 | 78.8 | 95.1 | 139.0 | 151.1 | 109.3 | 124.4 | 107.4 | 43.3 |
| Stress, psi | 893 | 756 | 834 | 1017 | 1106 | 799 | 984 | 980 | 416 |
| Initial thickness, in. | 0.195 | 0.199 | 0.202 | 0.180 | 0.183 | 0.202 | 0.187 | 0.186 | 0.019 |
| Final thickness, in. | 0.122 | 0.134 | 0.133 | 0.103 | 0.107 | 0.125 | 0.115 | 0.119 | 0.020 |
| Deformation, in. | 0.073 | 0.065 | 0.069 | 0.077 | 0.076 | 0.076 | 0.072 | 0.067 | 0.014 |
| Strain, in. per in. | 0.377 | 0.326 | 0.343 | 0.429 | 0.417 | 0.382 | 0.390 | 0.364 | 0.069 |
| Area, sq in. | 0.120 | 0.108 | 0.118 | 0.142 | 0.141 | 0.140 | 0.128 | 0.110 | 0.023 |

kernel moistures (25 to 35 percent), a yield point was not clearly defined, but a definite change in the slope of the force curve was usually observed. In this case, the breaking point was established at the point where the slope of the force-curve changed. For each kernel the initial thickness, breaking strength and yield point thickness were obtained. For each ear 10 kernels were tested for each region (butt, middle, tip).

The shelled cob was sawed into six 1-in.-long sections resulting in two specimens per ear region. Each specimen was placed horizontally between the plates of the Rinck-McIlwaine tester and initial diameter, breaking strength and breaking diameter readings determined, similar to those of the kernels. Initial cob diameter was taken as the distance between the plates at a 10-lb load during the cob strength test. At this force, the glumes were crushed and laid flat against the cob surface and cob deflection was still at a minimum. Moisture contents of cob sections and kernel were obtained by oven-drying at 102 C. A detailed description of the testing and recording equipment may be found elsewhere (8).

Laboratory Shelling

A shelling device consisting of a combine cylinder, concave, and beater assembly was used for the laboratory-shelling tests which were run at 480 (cylinder) rpm with cylinder-concave clearance of 1 $\frac{3}{8}$ -in. in front and $\frac{5}{8}$ -in. clearance at the rear. For each variety a total of 30 individual ears were tested throughout the season. Each ear was husked, length and diameter measured, and run through the sheller in a lateral direction. All material from each ear was taken from the collection pan before testing another ear.

Five times during the harvesting season about 10 ears of corn were selected at random in the field for each variety. The husks were removed and the ears threshed at the rate of 4 to 5 ears per sec, through the middle section of the cylinder, in an attempt to

simulate field-harvesting feeding rates. A grain sample was taken and grain moisture content determined.

Field Shelling

For each grain variety samples were obtained from field-shelling operations. A John Deere 45 combine was used for these tests. Samples were collected from the clean-grain discharge spout. Machine adjustments were the same for all tests and cylinder-concave clearances and cylinder speed identical to those used in the laboratory tests. Field testing was spread throughout the harvesting season over a large range of grain moisture content.

Kernel Damage Determination

The grain samples were taken to the USDA Agricultural Research Service grain storage and research laboratory at Ames, Iowa, for determinations of fines and kernel damage. Each sample was weighed and screened with a 12/64 sieve. The fines were weighed and expressed as percentage by weight. The screened sample was used for damage determination. Two subsamples of approximately 40 to 45 grams were obtained by dividing the original sample with a grain divider.

Kernel damage was defined as the percentage by weight of all kernels having breaks, cracks, or other injuries in their seed coat. Each kernel was thoroughly inspected for fissures, cracks, or breaks in the seed coat, and the damaged ones were separated from the whole, sound kernels. A special well-lighted booth was constructed to make inspection easier. The fractions were weighed and damage calculated on a percentage by weight basis for each subsample and the two averaged. The total damage was the sum of the fines and damage obtained by visual inspection.

Results and Discussion

Mean values of the most important kernel and cob properties for varieties 1 through 5 are given in Tables 1 and 2. Also included are regional means (butt, middle, tip) and least significant

differences for each variety. More detailed data may be found elsewhere (8).

Some of the properties determined were correlated with moisture content. Kernel strength and stress were negatively related to moisture; kernel strength increased as they dried. Kernel size (initial thickness and area) were positively related to moisture, indicating kernel shrinkage as they dried. The relationship of kernel strength and kernel moisture is shown in Fig. 2. Varieties 4 and 5 had significantly higher strength than varieties 2 and 3. Varieties 1 and 4 and especially 5 were more sensitive to moisture content than were the other varieties.

Kernel detachment force varied relatively little between varieties, except for variety 2 which had a detachment force significantly lower than the other varieties. Detachment force also seemed independent of kernel moisture.

Generally, variety 2 was characterized with low detachment force, low kernel strength, small round kernels, small cob diameter and high cob strength. Variety 5 was characterized with high detachment force, high kernel strength, large flat kernels, large cob diameter and low cob strength. Variety 4 had strong, large kernels with large kernel strains at seed coat rupture. Variety 1 was characterized with average values for the properties tested.

Kernel-damage and moisture-content results for the field-shelling and lab-shelling tests are summarized in Table 3. The damage figures are as determined by the visual inspection method and do not include fines.

Relationship of damage and kernel moisture when plotted on log-log paper resulted in a straight line. Varieties 1 through 4 had damage-moisture correlations significant at the 1 percent level. The same correlation was non-significant for variety 5. One of the reasons for the lack of significance was the short range of moisture content for

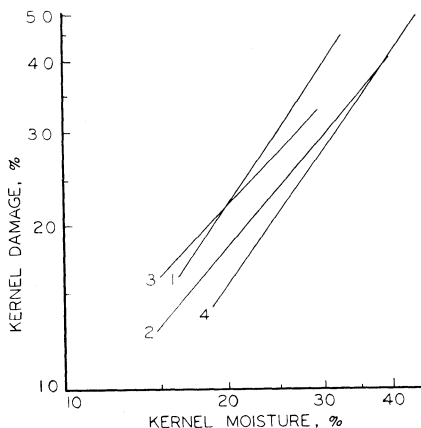


FIG. 3 Relationship of kernel damage and moisture content for varieties 1 through 4.

TABLE 2. MEAN VALUES OF COB PROPERTIES FOR VARIETIES 1 THROUGH 5

| Property | Variety | | | | | Region | | | Least significant difference, 5 percent level |
|-----------------------|---------|-------|-------|-------|-------|--------|--------|-------|---|
| | 1 | 2 | 3 | 4 | 5 | Butt | Middle | Tip | |
| Cob moisture, percent | 42.5 | 36.2 | 41.7 | 49.0 | 46.2 | | | | |
| Cob strength, lb | 173.0 | 187.2 | 135.0 | 168.8 | 142.8 | 143.2 | 169.6 | 171.2 | 49.6 |
| Initial diameter, in. | 1.129 | 1.037 | 1.105 | 1.075 | 1.262 | 1.180 | 1.133 | 1.052 | 0.083 |
| Final diameter, in. | 0.863 | 0.718 | 0.886 | 0.787 | 0.993 | 0.923 | 0.855 | 0.769 | 0.130 |
| Strain, in. per in. | 0.237 | 0.310 | 0.203 | 0.270 | 0.214 | 0.220 | 0.248 | 0.272 | 0.076 |

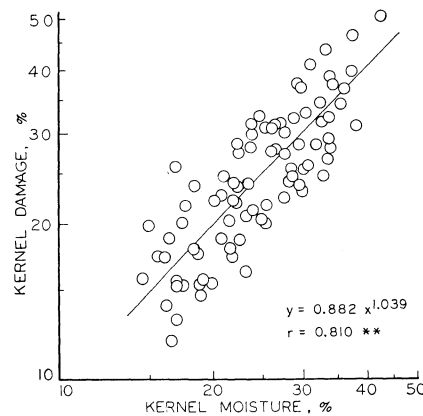


FIG. 4 General relationship of kernel damage and moisture content.

the damage data available for this variety.

To compare mechanical damage for the various varieties, a graph including varieties 1 through 4 was drawn (Fig. 3). Variety 5 was not included because of the nonsignificant correlation between damage and moisture content. Between a range of 20 to 30-percent moisture content, variety 4 had the lowest damage following by variety 2. Varieties 1 and 3 had similar damage at 20 percent moisture, but at 30 percent moisture, variety 1 had about 6 percent more damage. The difference between variety 4, with the lowest damage, and variety 1, with the highest damage, was about 6 to 12 percent damage in the moisture range of about 18 to 32-percent moisture. The one important fact is that the slope was approximately the same for all varieties; that is, kernel damage decreased as moisture content decreased.

If a 25 percent limit is set for mechanical damage for the varieties tested, then harvesting could be started at about 28-percent moisture for variety 4, 26-percent moisture for variety 2, 22.5-percent moisture for variety 3 and 21-percent for variety 1. Assuming a drying rate of 0.3 percent of moisture per day in the field, harvest would have to be delayed 15 days for variety 1 over variety 2 since both of these varieties mature in about the same growing time. A delay in the harvest increases harvesting costs and losses and increases safety hazards due to adverse weather conditions in the late season.

A general relationship for mechanical damage versus moisture content, which included all varieties, was established. A log-log plot of this relationship is shown in Fig. 4. An equation for the regression line is $y = 0.882 \times 1.039^x$, where y is the mechanical damage and x is the kernel moisture content. This equation can be used to predict mechanical damage from grain moisture content. The correlation coefficient was 0.810, which was significant at the 1-percent level. The r^2 of 0.653 indicates that 65.6 percent of the variation in damage can be accounted for by the difference in kernel moisture content.

One of the objectives was to determine if there were any differences in kernel damage between the shelling methods (field shelling, lab shelling a group of ears and lab shelling individual ears) used. When inspecting the damage versus moisture content regression lines for the five varieties, no differences between the shelling methods were detected. A typical variety relationship of kernel damage and kernel moisture is shown in Fig. 5. Points from all three shelling methods were distributed on both sides of the regression lines. From visual inspection of all regression lines, it was concluded that there were no significant differences in damage by the shelling meth-

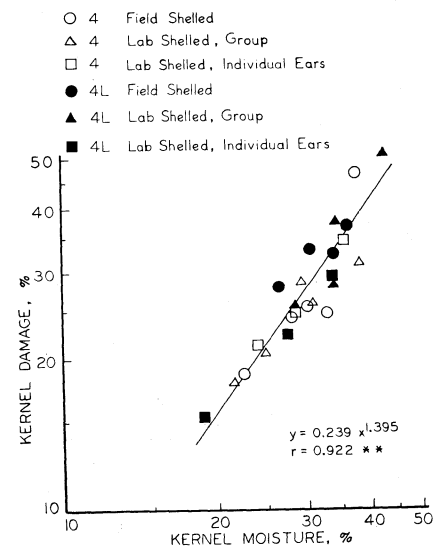


FIG. 5 Relationship of kernel damage and moisture content for varieties 4 and 4L.

TABLE 3. MECHANICAL DAMAGE FOR VARIOUS SHELLING METHODS USED

| Variety | Field shelled | | Lab shelled (group) | | Lab shelled (individual ears, 10-ear average) | |
|---------|--------------------------|------------------------|--------------------------|------------------------|---|------------------------|
| | Kernel moisture, percent | Kernel damage, percent | Kernel moisture, percent | Kernel damage, percent | Kernel moisture, percent | Kernel damage, percent |
| 1 | 29.0 | 66.4 | 27.2 | 31.1 | 30.5 | 40.6 |
| | 26.2 | 30.5 | 25.3 | 30.3 | 24.0 | 29.9 |
| | 23.2 | 20.6 | 23.9 | 27.9 | 16.5 | 18.5 |
| | 22.0 | 23.8 | 20.8 | 22.4 | | |
| | 17.8 | 21.4 | 17.4 | 19.8 | | |
| 2 | 29.3 | 37.2 | 29.5 | 23.6 | 27.6 | 30.0 |
| | 23.2 | 16.1 | 21.8 | 17.2 | 19.2 | 15.6 |
| | 19.0 | 14.5 | 17.0 | 15.1 | 16.5 | 11.9 |
| | 17.0 | 13.0 | 14.7 | 15.6 | | |
| | 15.0 | 19.7 | | | | |
| 3 | 26.2 | 27.2 | 26.3 | 30.9 | 24.8 | 32.2 |
| | 22.0 | 22.0 | 22.7 | 27.3 | 18.5 | 17.7 |
| | 20.9 | 18.7 | 22.3 | 23.5 | 15.7 | 17.2 |
| | 18.7 | 17.5 | 18.5 | 23.3 | | |
| | 17.0 | 15.6 | 17.0 | 25.8 | | |
| 4 | 37.5 | 46.4 | 38.2 | 31.0 | 35.6 | 34.2 |
| | 33.1 | 24.7 | 31.4 | 25.8 | 28.6 | 24.6 |
| | 30.1 | 25.4 | 29.5 | 28.5 | 24.0 | 21.2 |
| | 28.2 | 24.2 | 25.0 | 20.3 | | |
| | 22.6 | 18.6 | 21.6 | 17.8 | | |
| 5 | 33.3 | 43.3 | 33.7 | 26.3 | 32.5 | 34.3 |
| | 30.0 | 23.7 | 31.9 | 28.1 | 28.8 | 32.0 |
| | 23.9 | 31.3 | 26.6 | 27.6 | 22.3 | 28.6 |
| | 23.5 | 23.6 | 21.0 | 24.6 | | |
| | 21.5 | 20.1 | | | | |
| 2L | 37.3 | 39.4 | 33.8 | 38.7 | 25.3 | 21.7 |
| | 27.7 | 27.3 | 32.7 | 31.5 | 19.9 | 15.3 |
| | 25.3 | 20.0 | 29.7 | 37.0 | 16.1 | 17.2 |
| | 22.1 | 21.8 | 20.1 | 22.0 | | |
| | 17.4 | 15.1 | 16.2 | 13.9 | | |
| 4L | 42.9 | 53.2 | 42.8 | 50.5 | 33.7 | 29.3 |
| | 36.1 | 36.5 | 34.3 | 37.3 | 27.6 | 22.3 |
| | 34.0 | 32.5 | 34.0 | 28.1 | 18.8 | 15.2 |
| | 30.3 | 33.1 | 28.5 | 25.5 | | |
| | 26.6 | 27.9 | | | | |

ods used in the experiment. Similarly, the points for the early and late-planted corn (varieties 2, 2L, 4 and 4L) were well distributed on both sides of the regression lines. It was, therefore, also concluded that there were no significant differences in kernel damage obtained by early and late planting.

Fig. 4 illustrates that, in general, kernel damage is highly correlated with kernel-moisture content. However, Fig. 3 illustrates that the kernel-damage- and kernel-moisture relationships varied among the varieties tested. Since some of the physical properties, such as kernel strength, kernel strain, kernel size and others are dependent on kernel moisture content, it would seem logical that damage should be expressed in terms of these variables rather than moisture content. Hence, the multiple linear-regression approach was used to examine the importance of the various independent variables.

Multiple Regression

The first model examined included all the independent physical and morphological properties' variables for which data was available. This model was

$$\hat{Y} = B_0 + B_1Y_1 + B_2Y_2 + \dots + B_{15}Y_{15} + B_{16}Y_{16} \dots \dots \dots [1]$$

Identification of the variables and results of the regression computations are shown in Table 4. Data used for the multiple linear regressions consisted of ear averages from the physical properties tests and the lab-shelling tests.

Since these two tests were performed on different ears (because of the destructive nature of the physical properties tests), ears from the two tests were matched on the basis of moisture content.

The multiple regression was based, therefore, on the assumption that the physical properties of two ears of the same variety and with approximately the same kernel moisture were not significantly different. The analysis of covariance of the pertinent independent variables (physical properties), with moisture content as the covariate, reveals, however, that significant differences can be expected for the physical

properties of two ears of equal moisture.

Since differences for the physical properties between two matched ears can be expected, the results of the multiple-linear regression should not be used for predicting kernel damages. They serve, however, as a useful indicator of which variables are contributing toward mechanical damage.

In the first model (equation [1]), 57.9 percent of the expected damage could be accounted for by the regression equation. Since the t values for most variables were nonsignificant at the 20-percent level, some of the less significant variables were dropped from the model to make others more significant. This was done by dropping each time the least-significant variable from the regression computations. This procedure was followed until all the variables remaining in the equation had t values significant at the 5-percent level.

A regression model obtained by this procedure is

$$\hat{Y} = B_0 + B_2Y_2 + B_3Y_3 + B_4Y_4 + B_5Y_5 + B_7Y_7 \dots \dots \dots [2]$$

Table 5 summarizes the results. All the B quantities were significant at the 5-percent level or greater, and the multiple R^2 was 0.16, indicating that the regression accounted for 51.6 percent of the total sum of squares. Only a small reduction in the multiple R^2 occurred with the reduced model. This reduced model indicates that detachment force, kernel strength, initial and final kernel thickness and cob strength are important factors contributing to kernel damage.

A positive influence on damage is shown by detachment force, kernel deformation and cob strength and a negative influence by kernel strength.

TABLE 4. RESULTS OF LINEAR MULTIPLE REGRESSION OF KERNEL DAMAGE FOR MODEL EQUATION [1]

| Source | Degrees of freedom | Sum of squares | Mean square |
|----------------------------|--------------------|-------------------------|------------------|
| Regression | 16 | 3,548.6 | 221.79 |
| Residual | 39 | 2,573.4 | 65.98 |
| Total | 55 | 6,122.0 | |
| F = 3.361 | | Multiple $R^2 = 0.5796$ | $t_{05} = 2.004$ |
| Standard error = 8.123 | | $R = 0.7613$ | $t_{20} = 1.297$ |
| Variable | b value | Std. error of b | t value |
| \hat{Y} Damage | -151.43 | 114.13 | -1.326 |
| Y_1 Kernel moisture | 0.415 | 0.637 | 0.650 |
| Y_2 Detachment force | 4.415 | 2.355 | 1.874 |
| Y_3 Kernel strength | -0.301 | 0.261 | -1.152 |
| Y_4 Initial thickness | -302.27 | 909.62 | -0.332 |
| Y_5 Final thickness | 828.89 | 1430.4 | 0.579 |
| Y_6 Cob moisture | -0.258 | 0.315 | -0.818 |
| Y_7 Cob strength | 0.0709 | 0.054 | 1.312 |
| Y_8 Initial diameter | -22.41 | 38.09 | -0.588 |
| Y_9 Final diameter | 35.47 | 32.37 | 1.095 |
| Y_{10} Kernel area | 211.57 | 232.03 | 0.911 |
| Y_{11} Kernel strain | 272.03 | 282.68 | 0.962 |
| Y_{12} Kernel stress | 0.0226 | 0.0312 | 0.726 |
| Y_{13} Cob strain | 16.28 | 22.86 | 0.712 |
| Y_{14} Rachis-pith ratio | 1.243 | 6.221 | 0.199 |
| Y_{15} Ear length | -1.172 | 1.631 | -0.718 |
| Y_{16} Ear diameter | -3.462 | 1.244 | -0.278 |

Conclusions

1 As the kernel-moisture content decreased, the kernel size decreased, indicating kernel shrinkage as they dried.

2 Kernel strength and stress increased as kernel moisture decreased.

3 Kernel detachment force was independent of kernel moisture or other kernel properties.

4 As the kernel moisture decreased, kernel damage decreased.

5 No differences in kernel damage were obtained for field shelling and lab shelling of ears.

6 Planting date did not affect kernel damage.

7 The most important plant properties influencing mechanical damage were kernel detachment force, kernel strength, initial and final kernel thickness (kernel deformation), and cob strength. Low kernel damage was associated with low detachment force, high kernel strength, low kernel deformation, low cob strength.

8 By changing plant characteristics, such as reducing detachment force and increasing kernel strength, it should be possible to reduce kernel damage during combining.

Summary

Five varieties of corn, each with different ear characteristics, were planted in a replicate randomized-block design on two planting dates. The corn was used for field shelling, lab shelling and physical properties experiments at various time intervals beginning at about 35 percent kernel moisture until it had dried to 15 percent moisture.

Physical properties determined were kernel-detachment force, kernel-breaking strength under compression, kernel strain at failure, radial cob strength in

TABLE 5. RESULT OF LINEAR MULTIPLE REGRESSION OF KERNEL DAMAGE FOR MODEL EQUATION [2]

| Source | Degrees of freedom | Sum of squares | Mean square |
|----------------------------------|--------------------|---------------------------------|-------------------------|
| Regression | 5 | 3,158.9 | 631.8 |
| Residual | 50 | 2,963.1 | 59.6 |
| Total | 55 | 6,122.0 | |
| Standard error = 7.698 | | Multiple R ² = 0.516 | t ₀₅ = 2.004 |
| F = 10.661 | | R = 0.718 | |
| Variable | b value | Std. error of b | t value |
| Y ₁ Damage | -34.79 | 23.80 | -1.462 |
| Y ₂ Detachment force | 6.752 | 1.638 | 4.120 |
| Y ₃ Kernel strength | -0.1292 | 0.0438 | -2.947 |
| Y ₄ Initial thickness | 608.17 | 138.95 | 4.376 |
| Y ₅ Final thickness | -602.35 | 112.41 | -5.358 |
| Y ₇ Cob strength | 0.0649 | 0.0311 | 2.085 |

compression and cob strain. For each ear tested, 30 determinations were made for kernel properties and six determinations for cob properties.

The variation in kernel detachment force and most of the cob properties could not be related to moisture content or other pertinent variables.

Kernel strength was negatively correlated to kernel moisture content and differed among varieties. Kernel stress-moisture relationships were similar to strength-moisture relationships.

Kernel size (initial thickness and cross-sectional area) was correlated with moisture content, indicating shrinkage of kernels as they dried.

A laboratory-shelling device was constructed from conventional combine parts. Laboratory-threshing and field-combining tests were conducted simultaneously for the purpose of kernel-injury comparison. No differences in kernel damage between field-shelled and lab-shelled samples could be detected. Kernel damage was determined by careful visual inspection of samples. Kernel damage was positively related to kernel moisture. This mathematical relationship was

$$y = ax + b \dots \dots \dots [3]$$

where $y = \log_{10}$ damage and $x = \log_{10}$ moisture content.

A multiple-regression approach was used to provide information concerning the influence of physical properties of the cobs and kernels on kernel damage. The factors that affected kernel damage were kernel detachment force, compressive kernel strength, kernel deformation and compressive cob strength.

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